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# SOLAR THERMAL PROPULSION FROM CONCEPT TO REALITY

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SOLAR THERMAL PROPULSION
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Abstract

Solar thermal propulsion's multiple facets were studied and its application was looked at briefly. The efficiency and capability of select solar propulsion components were tested. During my brief tenure, several small projects were begun, some completed. A calorimetry experiment tested the power output of the existing rigid concentrator. The process of constructing and testing an inflatable concentrator for slope errors and its power output was initiated. Slope errors will be measured using laser ray tracing techniques. A shutter was designed to quickly allow or block the passage of light onto the test subject in order to take more accurate measurements. Finally, different absorber, thruster, and propellant types and combinations were studied. Phillips Laboratory has been testing several different components in various important areas over the past 13 years. The ground tests will eventually provide enough information to build flight hardware. This culmination into several flight tests is the next step to reality of solar thermal propulsion.

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Introduction

A solar thruster uses the sun's radiant energy to produce kinetic energy. Since the sun's heat is free, solar thermal propulsion may one day be a desirable form of orbit transfer for satellites. It creates thrust by collecting and focusing the sun's powerful rays into an absorber using a concentrator. The absorber collects the heat and transfers it to the fuel. The heated fuel expands and is forced through a nozzle. Because of the particles being forced out the aft end, the rocket is pushed forward with the same amount of force, or thrust. This, Newton's Third Law, is the basis of rocket science. The result of the conversion and expansion (no combustion) is efficient thrust created from a relatively lightweight and reusable vehicle.

Concentrator

The differences between the space-applicable, inflatable concentrator and the rigid concentrator in the laboratory were observed. Although rigid concentrators are great for testing in the lab, a much easier space deployable system is needed to make solar propulsion a viable and workable concept in space. In space weight and volume requirements can be met with lightweight and packageable inflatable concentrators. Inflatables are cheaper to produce than older forms of mechanically erected systems. Before flight, the testing of these inflatables for deployment capability, structural strength, and concentration efficiency must be performed to assure reliability. During this summer, time was dedicated to the testing the concentration of the inflatable verses that of the rigid concentrator to determine if this design packageability and reinflation was as proposed by the contractor.

Construction of the rigid concentrator in the lab included using 228 spherically shaped mirrors angled to simulate an off-axis paraboloid. In combination with a heliostat, or solar furnace, absorbers and thrusters are tested. The

heliostat is a series of flat mirrors, all lying on the same plane, that directs the sunlight into the lab and onto the concentrator. This allows us to work inside away from the uncomfortable and harmful to the delicate concentrator earth elements. Lab personnel manufactured this concentrator to have a 10,000 to 1 geometric concentration ratio, and to focus the light into a focal point 3.2 inches in diameter. When the concentrator was first tested for optical accuracy the RMS slope error was rated at 3 mrad and the assigned power was approximately 24.7 kW during the winter. It was tested again this summer to determine the degradation, but not to the same extent. A simple calorimetry experiment found the power output to be 18.21 kW during this summer, although a laser ray tracing wasn't performed to discover slope accuracy as before. To measure power, a calorimeter was easily made from an insulated ten gallon fishtank filled with darkened water to absorb the heat. A stirrer maintained uniform temperature throughout the tank. The insulation stopped most heat loss and helped give us more accurate readings. The temperature of the water remained almost constant for quite a while after the sun was covered, further showing the effectiveness of the insulation. The power was found by measuring the change in heat over a period of time.

Similar rigid concentrators may be made available for space flights and testing, although they are heavy and hard to build. It is not recommended, or even feasible, to use such a rigid concentrator in space. Therefore a lighter more packageable concentrator must be developed. Phillips Laboratory, Edwards, has the opportunity to be first to ground test an inflatable concentrator. The space application of these highly accurate concentrators requires them to be inexpensive, compact, light, and self deployable. This is the purpose of developing and testing inflatable concentrators. They are low in cost because they are easier to develop and to produce, in addition to the low launch cost due to low mass, and less time and people needed to deploy it. A space-applicable inflatable concentrator will generally be an off-axis elliptical section of a paraboloid because the incident light entering a paraboloid is concentrated onto one spot if the light shines directly on the projected minor diameter. Two of these paraboloidal sections are used to increase the performance of the system. The nature of these off-axis paraboloids requires them to be off to the sides, not only because of the necessity to move the system in any direction at

any time, but also to allow for the rocket plume to exhaust without any interference. The most simple designs look like a clam shell or a lens. They are simple because they are composed of a transparent canopy seamed together around the perimeter to a reflector. The first film, closer to the sun, would be as clear as possible to allow most of the light to hit the second film. The second film would be the reflective surface that concentrates the light into a focal point. As stated earlier, two of these ellipses concentrate light into two absorbers. An inflatable torus and three inflatable or foam-rigidized beams help support each concentrator and help them to keep their shape. There are also foam inflated and rigidized reflectors in development.

The trick is to construct a concentrator with a feasibly small slope accuracy error and surface error. They must also be large enough to focus the required amount of energy into the heat exchanger of absorber. In space, this would mean deploying a concentrator over 100 feet in projected diameter with slope accuracy error less than 2 mrad RMS. In a perfect world the reflective surface would be a single piece, but for now existing concentrators are seamed and gored. They consist of several strips of reflective material seamed together radially on-axis, like the spokes on a wheel. The reflector is tailored together just as a football is sewn together from several flat pieces. This tailoring causes weak points in the overall strength as well as surface and slope errors. It is very difficult to create an off-axis paraboloid's curvature in only one piece, but it is possible with the new spray casting on mandrels approach. In constructing our seamed and gored, clam shell concentrator, we first set up an ellipse shaped airtight pool in order to pull a vacuum. The vacuum pulled the reflective film into its correct off-axis paraboloidal shape. Then we will attach a clear film to the top of the reflective film and inflate. The reflector will be attached to the torus and then the torus to a stand. This will allow us to test the torus strength and capability to sustain the elliptical shape. If the torus works here on Earth, it may work in space due to the fact that there is one less unit of gravitational force in space. We will also be able to test the ellipse's optical output with similar experiments to the earlier calorimetry experiment mentioned above, and laser ray tracing experiments. Finally with the existing test stand, thrusters can be tested with this new technology.

Shutter

One problem during the testing of the concentrator with calorimeters or thrusters involves the accurate reading of data. A shutter of some type is required to instantly obstruct or unobstruct the sunlight from shining onto the test object. This allows us to more accurately gage temperature and time without other variables changing. For example during the fishtank calorimetry experiment, we calculated power by measuring heat vs. time. To accurately do this, the experiment had to begin and end at marked times. This is accomplished with a shutter that can quickly open and close. The shutter, while open, allows for all of the light to completely illuminate the test object, but when closed, isolates the test object from light. The lab setup includes a heliostat that directs the sunlight through a door onto a concentrator and then onto the test stand. The mechanical sliding door between the heliostat and the concentrator is functional but is very slow because of its size, but fortunately allows all of the light through when open. A shutter is required to withstand the heat of the extra light long enough for the door to close. The shutter may be placed anywhere in the lab setup. This may include allowing the light to hit the concentrator at all times and placing the shutter between the concentrator and test stand. A shutter there would have to endure more intense light on a smaller area. However, if it is placed near the heliostat it would have to be large, and heavy, to block all of the light. A shutter in either position would need to be collapsible and able to move quickly. The larger, heavier model would be hard to move, but the smaller model would have to collapse into less space.

The lab's new design is of the smaller, more durable type. The design is similar to Venetian blinds. Using several sheets of stainless steel tied together to be able to rotate into position in synchronous fashion. It was able to withstand high temperatures for a long enough time to allow the door to open and close. Sheets of stainless steel were strung together twice on each end through slots. Two of these cables were used as draw strings, while the other two were used as spacers. The draw strings are threaded through the middle of each side of each plate. The spacer cables attached at one corner of each side allow the weight to cause the plates to lie almost vertically when deployed. There are some problems. The plates will not lie flat because of interference caused by the draw

strings. Slotting the holes reduced this problem by creating more room and less friction. The horizontal placement of the plates also causes friction and results in the need of great force to retract the shutter. Currently the shutter is manually operated, but eventually the shutter will be automated. Other problems included heat radiating from the sheets of steel. The heat might have disturbed the temperature readings within the tank since the shutter was so close to the tank. Also there were some friction problems associated with the sheets deploying and retracting modes. Although the vanes were not completely shut or flat, letting some light through, the readings were adequate: a sudden increase in temperature after the shutters were opened and a level slope on the graph of temperature vs. time after the shutters were closed indicated the problem of the radiating heat. These readings showed the shutter worked satisfactorily, however.

Thruster

The thruster is composed of an aperture to let light through, and a heat exchanger or absorber. The heat absorber's main function is to conduct the radiant thermal energy through the wall of the heat exchanger, then transfer the heat to a propellant. It would be ideal if the propellant gas absorbed all of the heat without an exchanger. Unfortunately the gas is transparent to sunlight for our intents and purposes and most radiation passes through it. Some means of heat exchange is needed; the solar energy must be absorbed by an exchanger both in contact with the solar energy and the propellant. Two of these best types of absorbers are being tested and streamlined for flight tests. The first type, Black Body Cavity Absorbers, consists of an insulated tubelike cavity with a wall both in contact with the light and the fuel. Sometimes running the cold fuel through the cavity regeneratively cools the absorber cavity, to prevent the thruster from melting. The temperature is limited by the heat absorptivity of the absorber and the temperature the materials can withstand. The second type, the Volumetric Absorber, traps the solar energy inside the thruster behind a window. To impart this energy into the fuel, either porous material is placed in the chamber or small particles are placed in the propellant for heat exchange purposes. The major disadvantage of the this system could be the weight of the absorbent particles. If more particles are added, or bigger particles are used, more energy can be absorbed and therefore more heat can be

obtained. This creates an increase in thrust, but the added weight will lower the Isp (specific impulse) if the particles escape out the nozzle. A high temperature means that the Isp will also be high, to a point. Hydrogen gas can absorb great amounts of heat, possibly increasing Isp. A lighter material can solve the increased weight problem. Another way may be to induce the dissociation of the fuel because two H particles are lighter than one H2 particle. Hydrogen dissociation starts occurring at approximately 3800K. This high temperature (3000-4000K) is what gives solar propulsion a higher Isp than chemical propulsion. Solar propulsion requires only one propellant. This is another reason a solar propulsion system is lightweight; the concept requires no oxidizer, as opposed to chemical propulsion. Hydrogen is best suited as fuel because of its low molecular weight and its heat transfer capabilities. Hydrogen will be used as inflatant for the concentrator for the same reasons it's used as propellant.

Conclusion

As early as 2010 the government and private companies may be using this cheap and efficient upper stage as a means of orbit transfer. As of today, solar propulsion performance is between chemical and electric propulsion. Solar propulsion creates a higher, more efficient Isp than chemical propulsion; however it is capable of less thrust and takes longer to transfer payloads from Low Earth Orbit to Geosynchronous Equatorial Orbit (10-60 days). Because of the higher Isp, solar propulsion can carry more payload with less fuel. Electric propulsion may surpass solar propulsion in Isp efficiency, but it is incapable of creating high thrust. Therefore electric propulsion trip times are very long (180-300 days).

Since solar thermal propulsion is flexible, trip times can be varied to carry more payload in longer time, or less payload faster. As you can see, more industry will be turning towards solar thermal propulsion as it develops, because of its higher efficiency, lower cost, and better adaptability to missions needs. The concept has nearly become reality.

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Acknowledgments

I have enjoyed working at Phillips Laboratory, Edwards AFB. Over the past two years my knowledge of the multiple careers in technology has become more apparent to me. I have learned how an engineer works and the tasks of contractors. I also had the opportunity to share engineering experiences. The more I work with technology the more interesting the field appears. I would like to thank the Research and Development Laboratory (RDL) High School Apprenticeship Program and Phillips Laboratory, Edwards AFB for making these experiences possible. I will cherish the support and friendship from my coworkers for the rest of my life.

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SUBJECT: Laboratory Focal Point's "De-Sensitization" of Apprentice's Final Report

I have examined Karl J Iliev's ____________ 1996 SRP final report,
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Kristi K Laug

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